NeoBiota 89: 209–227 (2023)
doi: 10.3897/neobiota.89.106323
https://neobiota.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

Germany's first Action plan on the pathways of invasive alien species to prevent their unintentional introduction and spread

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Academic editor: Ingo Kowarik | Received 12 May 2023 | Accepted 7 November 2023 | Published 6 December 2023

Citation: Mayer K, Heger T, Kühn I, Nehring S, Gaertner M (2023) Germany's first Action plan on the pathways of invasive alien species to prevent their unintentional introduction and spread. NeoBiota 89: 209–227. https://doi.org/10.3897/neobiota.89.106323

Abstract

The increase in global trade and traffic networks contributes to the introduction and spread of invasive alien species, posing a threat to biodiversity. EU Regulation 1143/2014 addresses the prevention and management of invasive alien species and requires an action plan on the priority pathways of unintentional introduction and spread of invasive alien species by each member state. To this end, the first German action plan was developed for the German government in cooperation with relevant Ministries and authorities, scientists, administrative experts, stakeholder working groups and political as well as public deliberation processes. As a result, 14 priority pathways of unintentional introduction, escape or release and spread were identified, resulting in 24 targeted measures. Nineteen sectors will be involved in the implementation of these measures. Here we describe the development process and outcome of Germany's first action plan. By this, we aim making the process public and transparent, which can facilitate a revision of the action plan required at least every six years, and trigger broader European as well as national cooperation in the future.

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Keywords
Biological invasion, EU Regulation 1143/2014, measures, movement, prevention, prioritisation, routes

Introduction

Invasive alien species are a major driver of global biodiversity loss (e.g., Vilà et al. 2011; Bongaarts 2019; Pyšek et al. 2020). Hence national as well as international actions are necessary to prevent further environmental, social and economic impacts (CBD 2008). Many species have been introduced intentionally (Kowarik 2003; Hulme et al. 2008; Lambdon et al. 2008), but also unintentional introduction, release or escape and spread play an important role, especially in semi-natural habitats (Pyšek et al. 2011). In Europe, the importance of pathways differs largely among taxonomic groups. But ecological impacts in plants are much more frequent in intentionally introduced species than in those unintentionally introduced as contaminant to goods and commodities. Similarly, intentional release is the most important pathway for fish, while unintentional introductions are much rarer (Rabitsch et al. 2013; Nehring and Steinhof 2015). Also, for most taxa impact increases with the number of pathways with which a species is associated (Pergl et a. 2017).

The framework for pathway classification originally suggested by Hulme et al. (2008) has been adopted by CBD (2014) and has thus become a global standard for pathway classification. Pergl et al. (2020) tested this framework on European species and found it to be robust, though simple modifications are recommended to improve its usability. In addition to the knowledge base of Hulme et al. (2008), extensive data bases for other taxa were established, such as for forest pathogens (Santini et al. 2013) and marine alien species (Katsanevakis et al. 2013).

With respect to the targets of the CBD, EU Regulation 1143/2014 aims at managing invasive alien species of Union concern, preventing their further spread as well as covering early detection and rapid response at European level. Achieving this objective, various restrictions are set for intentional introductions of these species (Article 7 of EU Regulation), which was requested and appraised by scientists a while ago (Hulme et al. 2009). Especially with regard to unintentional introductions, escape or release of these species into nature and subsequent spread, each member state has to establish an action plan to manage the responsible pathways (Article 13). The goals of the action plan are to (1) identify the pathways which require priority action ('priority pathways') in the member states' territory and marine waters, because of the volume of species or of the potential damage caused by the species entering the Union through those pathways and (2) to implement appropriate measures to prevent unintentional introductions, escape and spread along these pathways.

Within three years of the adoption of the Union list, each Member State shall establish and implement one single action plan or a set of action plans to address the priority pathways it has identified. Recently, the first German action plan has

been adopted by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety taking into account the legal requirements according to the Federal Act on the Protection of Nature (BMU 2021). Here, we describe the contents of Germany's action plan as well as the method and cooperative process of its development.

Methods

Prioritisation of pathways

To address the first goal of the EU regulation, a previous study analysed 37 pathways of unintentional introduction and spread of invasive alien species into or within Germany and ranked them according to their species volume, i.e. the number of species per pathway (Rabitsch et al. 2018). For the prioritisation, Rabitsch et al. (2018) took into account (a) the species of Union concern as well as (b) the species that are categorised as invasive in Germany by the Federal Agency for Nature Conservation. However, according to Article 13 para 1 of the EU Regulation, the prioritisation of pathways should be based on the species of the Union list only (option (a) above), which included 37 species at the time when the study was prepared by Rabitsch et al. (2018). Given the small number of this selection, especially when compared with the number of alien species in Europe, about 14,000 (Roy et al. 2019), there was a risk of obtaining an inaccurate picture of the pathways' importance. Marine species, for instance, and important pathways in this context were underrepresented on the Union list. To account for this, in addition to the 37 species of Union concern, the analysis has been performed using a wider selection, namely all terrestrial, limnic and marine species expertly listed as invasive in Germany (93 species) (Rabitsch et al. 2018). This latter group also included all 12 species of the first extension of the Union list, which entered into force shortly after the pathway analysis had been completed. It even included several species of the second and third update of the Union list, although their listings only came into force in 2019 and 2022 respectively. In total, 130 invasive species have been analysed for the pathway prioritisation. Resulting from this was a list of 14 priority pathways which was used as a basis for developing an action plan for preventing introductions to, and spread within, Germany. It is debated, though, whether all invasions in all countries can be mapped onto the existing CBD pathway scheme (Faulkner et al. 2020). Still, with slight modifications, this framework seems suitable for Europe (Pergl et al. 2020). Accordingly, Rabitsch et al. (2018) used a slightly adapted version of the CBD scheme considering the pathways for each of the invasion stages introduction, escape or release, and spread. In our project some pathways had to be redefined and combined, to facilitate the assignment of pathways to relevant stakeholder groups (Box 1).

Box 1. Identified priority pathways for the introduction and spread of invasive alien species in Germany. The categories 1 to 4 follow the CBD pathway classification (UNEP 2014).

1) Escape from confinement
   - Botanical gardens
   - Ornamental plants
   - Pet trade/aquaristics/terraria/ornamental animals
   - Zoos (enclosures, public aquaria)

2) Contamination of transported goods
   - Contamination of soil, gravel, dead plants (e.g. hay, straw) or similar material (e.g. in earthworks or landscaping)
   - With material from garden centres and tree nurseries (e.g.potting compost) in or on plant bio-vectors

3) Stowaways in or on means of transport
   - Ballast water
   - Fishing and angling accessories
   - Growth/accumulation on the hull of ships
   - In or on devices/machinery/equipment
   - In or on humans or in their luggage (incl. tourism)
   - In or on motor vehicles (along roadways)
   - In or on trains (along rail-way lines)

4) Unassisted (corridor)
   - Unassisted dispersal along canals or waterways between river basins, lakes and seas

Development of the action plan

For the development of the proposed measures a step-by-step approach was used. Special attention was paid to build on already existing experiences in Germany, the European Union and worldwide concerning the prevention of unintentional introduction and spread of invasive alien species. Further, existing structures, such as federal or Länder (state) ministries, established public relations measures and existing associations were preferably addressed in this first action plan. These structures were used as they can be more easily addressed and monitored than private institutions; furthermore they are more realistic to leverage for pathway management than as yet non-existent structures and activities.

This resulted in a five-step process (Fig. 1): (1) We started the process with a broad literature review (considering studies from all over the world while focussing on the feasibility in Germany) to collect existing and proposed new approaches in pathway management of invasive alien species. (2) Expert consultations were carried out with stakeholders of all prioritised pathways and affected sectors. (3) The resulting list of proposed measures was subjected to a process of selection and aggregation, using a criteria catalogue for the prioritisation (see below). This led (4) to 24 proposed measures and (5) a deliberation process.

(1) Literature review on pathway management

As a first step, national and international measures and code of conducts for the management of the prioritised pathways were reviewed in 2018 and checked for their relevance and applicability for national concerns. We focused on national actions that were already implemented, in order to allow using existing structures and experiences. We also reviewed measures in countries and regions that are especially affected by

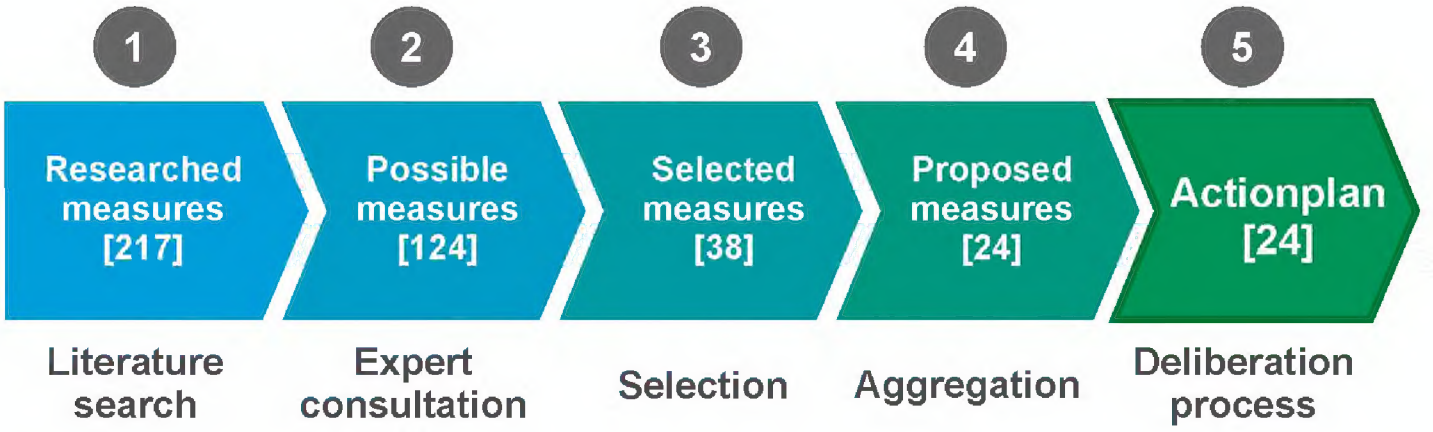

Figure 1. Consecutive steps in the development of the catalogue of measures for the first German action plan on the pathways of invasive alien species. The number of measures resulting from each step is given in square brackets. Thirty-eight out of the 124 possible measures were selected, aggregated and finalised to a list of 24 tangible measures that result in the action plan after a series of deliberation processes.

alien invasions (such as South Africa, Hawai'i and New Zealand). We searched for these plans and other directing measures by scientific databases (Web of Science) and other search engines using keyword combinations such as "action plan", "invasive alien species", "non-native", "biosecurity strategy", "weed and pest", "strategic plan" and other sector- and pathway-specific keyword combinations such as "ornamental plants", "contamination", and "ballast water" as well as backwards search of known documents. Then, we expanded the review on measures that were proposed in the literature but that were not implemented yet. Finally, the resulting list of potential measures was examined for gaps in the coverage of the prioritised pathways. This resulted in 217 measures to be investigated (Fig. 1).

(2) Expert consultations

As a second step, in intense consultations with experts of all affected sectors, the potential measures identified by the literature review were discussed to further develop, prioritise and substantiate measures as well as to discuss ideas for further measures. These consultations thus allowed to incorporate existing experience and knowledge into the action plan.

Nineteen sectors (such as agriculture, conservation, and transport) were identified for being responsible in implementing these actions i.e. were involved in pathway or species management (for a complete list of all sectors involved see Suppl. material 1). For each of these sectors associated experts were involved.

The experts comprised a heterogeneous group that included officials from various ministries, representatives from NGOs, registered associations, think tanks, coordination centres for invasive alien species, working groups, professors, and other specialists such as biologists from universities and various federal and private research institutions, laboratories, councils, state offices, airports, and transportation groups.

The number of experts consulted for each pathway analysis varied between 6 and 30, with an average of 11 experts being consulted per pathway. This was due to the

varying numbers of stakeholders involved in managing invasive alien species that were unintentionally introduced or spread along each pathway.

Additionally, the extent of prior actions taken, as well as the level of awareness and sensitization, varied notably among the different pathways. Some experts were consulted for only one pathway, while others were consulted for up to five pathways in a single session. Consequently, the duration of the individual consultations varied, ranging from 30 minutes to over two hours.

Experts were either interviewed bilaterally, or via individually prepared questionnaires. In total, 62 bilateral talks and 49 individual questionnaires were taken into account. Some discussions with experts were continued in follow-up consultations, in some cases spanning several months. The entire process was done in close cooperation and coordination with the German Federal Agency for Nature Conservation (BfN) and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Drafting the measures was also supported by a project-accompanying working group (PAG) with representatives from authorities, associations and science headed by the BfN, which met twice in Bonn. It proved very useful to bring in all sectors and stakeholders, not only for best exploiting existing knowledge, but also for preparing the ground for efficient and effective implementation.

(3) Selection of measures

An extensive list of 217 possible measures for preventing unintentional introduction and spread of invasive alien species along the priority pathways resulted from the literature review. Consultations with experts reduced this number to 124 measures whose application could be considered and should be discussed more intensively with regard to a manageable implementation in Germany (Fig. 1). This is even more important, due to the given limited German experience in the management of unintentional introduction and the spread of invasive species.

Through dialogue with experts, it turned out that the priority pathways and the respective possibilities for preventive measures differed in many respects, e.g. their degree of implementation. We therefore needed to assess each pathway individually rather than in a bulk approach.

To select a set of manageable measures from the list of 124 measures we performed a step-wise approach according to previously defined criteria (Table 1): Firstly, we determined already existing structures and activities at national or international level in the subject area, on which our potential measures could be based or linked to. Care was taken to explicitly keep those measures that build on experiences and (legal) regulations in Germany and the European Union (e.g. existing self-commitments by professional associations).

Secondly, we estimated the cost-benefit ratio for each suggested measure in accordance with Art. 13 Para. 4 EU Regulation. Measures that could make use of existing workflows, thus not needing extensive additional funds, and at the same time expected to have a broad and long-lasting impact, were given highest priority.

Table 1. Criteria for prioritisation of possible measures.

Builds on existing structures	High priority for measures that build on existing structures, regulations, recommendations, actions or activities in Germany, Europe or internationally
Cost-benefit ratio	High priority of measures with high benefit at low to medium costs
Costs low	Existing resources / personnel structures are sufficient
Costs intermediate	One-time additional funds required
Costs high	Permanent establishment of additional personnel structures and funds required
Benefit low	Local, short-term impact
Benefit intermediate	Regional, medium-term impact
Benefit high	National, long-term impact
One-off or long-term effect	Avoidance of one-off effects; if possible reformation of measure to achieve long-term effect
Avoiding possible conflicts with nature conservation	High priority for measures without potential conflicts with other nature conservation objectives
Synergies with other measures	Actions facilitating each other, within or between different pathways, were given priority

Additional selection criteria were the sustainability of a measure, the avoidance of conflicts with nature conservation, and synergies between different measures. Information, experiences and findings from the bilateral talks on the feasibility of a measure were taken into account during this process (see Table 1). Measures that did not meet or only partially met either of these criteria were either further adjusted or, where this was not possible or sensible, sorted out.

For example, for the pathway "fishing and angling accessories" one suggested measure was to build Crab barriers. During the selection process, however, it turned out that the respective costs would be very high. Further, this measure would not yield an additional nature conservation value, and the responsibilities were not clear. Therefore, this measure was not selected for inclusion in the action plan.

(4) Aggregation

The prioritisation resulted in up to four sensible and possible measures for each pathway (altogether 38 measures). Measures that were not selected were documented in a table for future revisions of the action plan (see Mayer et al. in press). These resulting 38 measures were aggregated into 24 measures (Step 4, Fig. 1). The aim of this aggregation process was to develop actionable sets of measures with clear assignment to specific stakeholders.

(5) Deliberation processes

After a set of measures was selected in step three and compiled into actionable sets of measures in step four, this list became the first draft of the action plan and had to go in step five through a number of deliberation processes according to the Federal Act on the Protection of Nature (BNatSchG), in which all the requirements from the EU Regulation are transposed into German law. As part of the procedure for drawing up the action

plan, the public was involved in accordance with § 40f BNatSchG: The draft of the action plan was available on a website of the BMU in September 2020 for a period of one month for public commenting. This resulted in 73 suggested changes, all of which were evaluated and 25 changes were subsequently incorporated into the draft action plan. A large proportion of the comments received related to the definition of responsibilities and the binding nature of measures. Above all, there were calls to introduce stricter controls and enforcements, and the measures were criticised for being formulated too loosely.

The revised draft of the action plan according to § 40d Abs. 1 BNatSchG was then decided and published by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU 2021) as a legally binding document after hearing the federal states in agreement with the Federal Ministry of Transport and the Federal Ministry of Agriculture.

Results

Structure of the German action plan

According to Article 13 para 2 of the EU Regulation, each Member State shall establish and implement one single action plan or a set of action plans to address the priority pathways. To make the best use of synergies among several pathways, stakeholders and some cross-pathway measures, we decided to develop one single action plan that addresses each prioritised pathway individually, rather than a set of action plans, i.e. one for each sector. A template was developed giving basic information for each pathway in a header, followed by short descriptions of required measures. In the head section, invasive alien species of Union concern that were, or could be introduced by, or spread along each priority pathway, are listed and involved sectors are mentioned. Subsequently, the overall aim of the measures is described.

The structure and content of the action plan are designed to meet the requirements of the EU Regulation. The description of single measures contains information about: (1) the targeting categories (according to Article 13 para 4 a-c) of the EU Regulation (i.e. raising awareness, minimizing contamination or border checks), (2) the specific aim of the measure, (3) responsible stakeholders and cooperation partners, (4) the target group, (5) a specific description of the measure (according to Article 13 para 2), (6) a rough cost-benefit analysis (according to Article 13 para 4), (7) a time table (according to Article 13 para 2) and (8) a paragraph about the documentation of the measure, since the action plan has to be revised at least every six years (according to Article 13 para 5).

Content of the German action plan

A list and short description of all 24 measures of the German action plan is given in Table 2. The complete action plan is currently only available in German (BMU 2021). Of the 24 specific measures, 16 are cross-sectoral and eight address stake-

Figure 2. Examples of issues addressed in the first German action plan on the pathways of invasive alien species **A** in or on humans or in their luggage (M20) **B** in ballast water of seagoing and inland ships (M13, M14) **C** in or on trains (along railway lines) (M21) **D** growth/accumulation on the hull of ships (M15, M16) **E** contamination of gravel (M10, M11) **F** unassisted dispersal along canals or waterways between river basins, lakes and seas (M22, M23, M24) **G** botanical gardens (M1, M2). M# means Measure number in Table 2. Photo credits: Tina Heger (**D**), Katharina Mayer (**C, E**), Stefan Nehring (**A, B, F, G**).

holders in only one sector. Four measures were laid out across different pathways. 50% of the measures have the aim to raise awareness, which is achieved by (a) public relation activities and by (b) educating and training relevant stakeholders on how species are spread along the prioritised pathways and possible consequences. The other 50% of the measures intend to minimise contamination of goods, commodities, vehicles and equipment by specimens of invasive alien species, including measures to tackle transportation of invasive alien species from third countries, which is done by (c) developing and publishing technical documents or by (d) addressing the need of targeted research projects. Examples of issues addressed in the action plan are illustrated in Fig. 2.

All measures build on existing structures, and the content was discussed and adjusted in accordance with individual stakeholders. The agreement of the stakeholders was seen as an important requirement for a successful implementation of the action plan.

As described above, this was done through a political deliberation process and by interacting with the stakeholders potentially involved in each of the considered measures.

Table 2. List and description of all 24 measures of the first German action plan on the pathways of invasive alien species. M: Measure; CPM: Cross-pathway measure.

Measure #	Pathways	Content	Stakeholders
M1	Botanical Garden	Application and further development of the "Principles for handling invasive and potentially invasive plant species in botanical gardens"	Association of Botanical Gardens in Germany
M2	Botanical Garden	Educating the public: public relation activities for visitors of the botanical gardens	Association of Botanical Gardens in Germany
CPM3	Pet trade/aquaristics/ terraria/ ornamental animals; Ornamental plants; In or on humans or in their luggage	Continuation and further development of web pages	Nature conservation authorities at various administrative levels
M4	Pet trade/aquaristics/ terraria/ ornamental animals	Implementing the "European code of conduct on pets and invasive alien species"	Pet trade and pet store (incl. online trade)
CPM5	Pet trade/aquaristics/ terraria/ ornamental animals; Ornamental plants; With material from garden centres and tree nurseries/ In or on plant bio-vectors	Invasion risk assessment of alien species	Federal Agency for Nature Conservation (BfN)
M6	Zoo (enclosures, public aquaria)	Raising awareness among professionals in animal care training	Bodies responsible for education in the Federal Ministry for Economic Affairs and Energy, ministries for education of the Länder, professional association of zoo keepers (BdZ e.V.)
M7	Zoo (enclosures, public aquaria)	Taking the European Code of Conducts on invasive species in Zoos into account	Animal parks, zoos, enclosures, public aquaria
CPM8	Ornamental plants; With material from garden centres and tree nurseries/In or on plant bio-vectors	Raising awareness among professionals in vocational trainings of gardeners, agriculturists and foresters	Bodies responsible for education in the Federal Ministry of Food and Agriculture; ministries for education of the Länder
M9	Ornamental plants	Application and further development of the recommendations for "handling invasive species" of the German Horticultural Association	German Horticultural Association (ZVG e.V.)
M10	Contamination of soil, gravel and dead plants	Consideration of the topic "minimising the introduction and spread of invasive species via contaminated material" in guidelines and working aids for sustainable building	Federal Ministry of the Interior, Building and Community (BMI) and Federal Office for Building and Regional Planning (BBR)
M11	Contamination of soil, gravel and dead plants	Educating the public and specialists about the proper disposal of green waste, garden waste and soil contaminated with invasive species	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), German Environment Agency (UBA), competent Länder authorities, Federal/Länder working group on waste (LAGA)

Measure #	Pathways	Content	Stakeholders
M12	In or on motor vehicles (along roadways)	Considering the handling of invasive species in technical documents for the planning, creation and maintenance of roadside green	Road construction administrations of the federal and Länder governments
M13	Ballast water	Examination of the Ballast Water Management Convention as part of the Experience Building Phase (EBP)	Federal Maritime and Hydrographic Agency (BSH), Federal Ministry of Transport and Digital Infrastructure (BMVI)
M14	Ballast water	Research on the transport and prevention of the introduction, escape or release of alien aquatic species with ballast water in inland navigation	Network of Experts from the Federal Ministry of Transport and Digital Infrastructure (BMVI, BSH, BfG)
M15	Growth / accumulation on the hull of ships	Raising awareness of pleasure craft owners	Diverse professional associations of boating and pleasure crafts
M16	Growth / accumulation on the hull of ships	Research on the transport of alien aquatic species by fouling on ship hulls	Network of Experts from the Federal Ministry of Transport and Digital Infrastructure (BMVI, BSH, BfG)
M17	Fishing and angling accessories	Development of a guideline for dealing with alien species in fishing activities	German Fishing Association (DAFV) and other fishing associations of the Länder
M18	Fishing and angling accessories	Consideration and further development of guidelines in dealing with alien species in aquaculture (edible and stock fish production)	Federal and Länder fisheries authorities, fisheries associations
CPM19	In or on devices / machinery / equipment	Raising awareness among specialists and the public	Respective stakeholders of correspondent actions
M20	In or on humans or in their luggage	Public-relations activities	Federal Agency for Nature Conservation (BfN), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)
M21	In or on trains (along railway lines)	Consideration and further development of technical documents for dealing with invasive species regarding the creation and maintenance of greenery along railway lines	German Railways and other railway transport companies
M22	Unassisted dispersal along canals or waterways between river basins, lakes and seas	Raising awareness among specialists	Federal / Länder Working Group on Water, Federal Water Management Associations
M23	Unassisted dispersal along canals or waterways between river basins, lakes or seas	Consideration of the handling of alien animal and plant species in technical documents of the water management, as well as the waterway and shipping administration	Federal / Länder Working Group on Water, Federal Water Management Associations
M24	Unassisted dispersal along canals or waterways between river basins, lakes or seas	Research on migration barriers and technical barriers in shipping canals	Federal Agency for Nature Conservation (BfN)

Discussion

The first German action plan contains measures to raise the awareness of public and specialised staff as well as measures to minimise the contamination of goods, commodities, vehicles and equipment by specimens of invasive alien species, including measures to tackle transportation of invasive alien species from third countries. The first and largest category, raising awareness, covers multiple public relation activities and further education of relevant stakeholders. The second category, minimizing contamination, contains the (further) development of technical documents and calls for research projects. With these proposed actions, the German action plan aims at managing the priority pathways of unintentional introduction and spread of invasive alien species, as required in response to EU Regulation's Article 13.

In accordance with EU Regulation 1143/2014, the management of single species is not the purpose of the German action plan. Neither is its aim to prevent deliberate introductions. This very important group of causes for biological invasions has to be tackled urgently, but action plans based on Article 13 of the EU Regulation are not the appropriate tool for this task. Specific pathway management could be a powerful lever for preventing the unintentional introduction and spread of alien species. The advantage of addressing the pathway instead of single species clearly is that respective measures can affect both known as well as yet unknown invaders spreading along that pathway. It remains to be seen whether the first German action plan is such a powerful lever for efficient prevention of the unintentional introduction, escape or release and spread of future invasive species.

Internationally, actions plans have been published and implemented for several decades. Within the last ten years the number of actions plans worldwide increased tremendously. As part of the literature review we surveyed 56 actions plans for potential and feasible actions in Germany, all published within the last twenty years. These action plans differ in their structure and focus (see Suppl. material 2). Regarding EU Regulation 1143/2014 on invasive alien species, the French action plan was the first, which was uploaded to the EIONET Reporting Obligations Database (ROD). In the meantime, the action plans of all member states will most likely have been published, however, generally in the respective national language. No formal exchange about the development and content of the action plans with other countries of the European Union has taken place. Hence, the conscious development of Europe-wide, synergetic effects was not possible for the first action plan.

However, since regular updates of the action plans are obligatory (the next one for all Member States is due in 2025), a cross-European cooperation should be considered for the future. One reason for the national approach taken during this initial process of developing an action plan was to build on existing national structures, which is most likely also valid for other similar national enterprises. The German action plan, hence, addresses in most cases specific stakeholders, with whom consultations and coordination had taken place beforehand. Regular updates (of the Union list as well as further developments of management techniques), also prevent invasions being

taken as a static event, but allow the dynamic response to changes in invasion and introduction dynamics.

In an exemplary short comparison of the German with the French action plan (Ministère de la Transition Ecologique 2022), different approaches but also commonalities become apparent, so that a desirable EU-wide harmonisation of specific measures seems desirable in the future. The French Action plan consists of 36 measures, structured in one table, focussing on four different topics: (1) Transversal measures, (2) Ornamental and horticultural use, (3) Domestic detention of invasive animals and (4) Aquatic and terrestrial corridors. Each of these themes contain five main operational tools: (A) Raising awareness, (B) Communication and training, (C) Management tools and actions such as legislative and regulative, (D) Control, biosecurity and surveillance such as guides to good practices and codes of conducts, (E) Research, expertise and knowledge. Ten columns describe the single measures, such as: operational tools, a title, spectrum of species and environments, the overall goal, context, target partners and stakeholders, description of the measure, associated actions, similar programs, timeline, priority, cost and the acceptability of the target actors. Hence the measures address raising awareness, and minimising contamination of goods as well as ensuring appropriate checks at the Union borders. The latter is missing in the German action plan. Compared to the German action plan, some measures of the French action plan are more binding. Some French measures include potential options and good practice examples added for better comprehension of the tasks. Target partners are sometimes precisely defined but sometimes also only broadly mentioned.

The EU Regulation describes that binding as well as voluntary measures shall be adopted (Article 13 para 2). The German action plan holds a mainly broad scope of measures and allows stakeholders to decide whether and how to implement their content. Nevertheless, stakeholders should document if and why certain measures have been implemented. Further, the German action plan has not addressed aspects like enforcement, control, border surveillance and biosecurity that are mentioned in several other action plans, for example in Australia and New Zealand (see Suppl. material 2), where border control and enforcement of certain measures are clearly defined in the action plan.

For instance, the first German Action Plan does not, in addition to the official controls by customs pursuant to Article 15 (see § 51a BNatSchG), specify any other appropriate checks at the Union borders as listed in the EU Regulation (Article 13 para 4 c). The extent to which stronger controls at the German borders are necessary should be reassessed in future action plans. In comparison to other national action plans which are more binding as well as precise (listed in Suppl. material 2), the first German action plan strongly counts on voluntary measures. During the drafting process it became obvious that in the given context legally binding initiatives are extremely complex and can only be realised later. These "shortcomings" of the German action plan were also identified during the deliberation process (public participation and the consultation of the Länder). However, the update of the Action Plan, which is currently being developed, will hopefully incorporate these suggestions.

Conclusions and future options

The action plan was adopted in a codified political deliberation process after participation of the public and consultation with the Länder by the responsible Federal Ministry for the Environment in agreement with two other Federal ministries in the sectors of agriculture and transport. Clearly, in democratic societies such political processes are of major importance. Science can offer advice, but the final decisions on which measures will be taken must take into account other arguments as well. These first measures, however, will help preventing the introduction and spread of alien species in Germany, and with future revisions, the action plan can constantly increase its effectiveness. Here, from a scientific point of view, particular attention should be paid to developing and establishing stronger and more binding measures.

This includes ensuring that, as far as required, appropriate checks at Union borders other than the official controls pursuant to Article 15 are additionally implemented (see EU Regulation 1143/2014 Article 13 para 4 c). Since a preventive approach regarding invasive alien species shall consider potential future invasions, it has to be discussed and eventually defined which kind of species, other than the species of Union concern shall be addressed by the action plan in the future. For this, a possible future adoption of a national list of invasive species, as specified in the EU Regulation (Article 12) and in the German Federal Nature Conservation Act (§ 54 para 4), could be helpful. This would further improve the protection of biodiversity in Germany.

In this context, the nature conservation risk assessments for alien species published by the BfN (e.g. Essl et al. 2011; Nehring et al. 2013, 2015; Rabitsch and Nehring 2022) could provide the necessary information for defining invasive species of national importance (Köck 2015).

Another promising approach in reducing future invasions is a closer cooperation with horticulture and pet trade. Labelling and, regarding the former, an increased supply and marketing of native plants have great potential (e.g. Humair et al. 2014). In this context it is important to note that the BNatschG does not aim to only protect biodiversity from invasive species but also promote the integrity of genetic diversity by allowing the planting and sowing from native provenances of plants in the open landscape, only, although exemptions are possible in certain cases (§ 40 para 1 No 4 BNatSchG; Skowronek et al. 2023). In addition, online trade, contributing significantly to the dispersal of ornamental plants worldwide, should be addressed more specifically (Humair et al. 2015).

Moreover, a European-wide cooperation in the revisions of the action plans should be envisioned. Strategies within the country as well as promising approaches on a conservation as well as political level could be exchanged, fostering broader trans-national cooperation. Such cooperation, coordinated by a European centre, was already suggested by Hulme et al. (2009).

Another future goal should be closer cooperation between different stakeholders as well as departments in order to tackle potential invasions risks before they become unmanageable (McNeely et al. 2001). Since in many cases costs amortize over time (Surkov et al. 2008; Richter et al. 2013), it is recommended to focus on opportunities

and cost-effectiveness of the proposed and future measures of the action plan rather than on the first upcoming costs. Closer cooperation as well as straightforward communication among decision-making authorities, funding authorities and other stakeholders, could be one way to go forward. Another option may be the setup of one national funding scheme for the prevention of invasive alien species, independently on the sector of expenditure.

Lastly, the current action plan was only the first one with a clear mandate to analyse existing pathways, i.e. having a more hind-sighted perspective. The updates need to anticipate future developments (e.g. Seebens et al. 2020; Roura-Pascual et al. 2021) and be more fore-sighted.

Acknowledgements

The underlying Research and Development project (FKZ 3518 82 0600) was funded by the German Federal Agency for Nature Conservation with funds from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. We thank our project supervisor, Annika Tiesmeyer, and the participants in the working group which was set up to support the project for the helpful and constructive discussions of feasible measures, gaps and practicable implementation. Further, we thank all bilateral dialog partners that assisted in identifying existing knowledge and activities as well adding to the process of developing appropriate measures. The article processing charge was funded by the Baden-Württemberg Ministry of Science, Research and Culture and the Nürtingen-Geislingen University of Applied Sciences in the funding programme "Open Access Publishing".

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Supplementary material 1

19 sectors identified and assigned to the 14 prioritised pathways

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Data type: docx

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Link: https://doi.org/10.3897/neobiota.89.106323.suppl1

Supplementary material 2

List of some countries or regions that have already implemented action plans or similar documents

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Data type: docx

Explanation note: Many international action plans are structured tabularly, sequencing according to the objectives or operational tools. The table describes some examples in more detail.

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